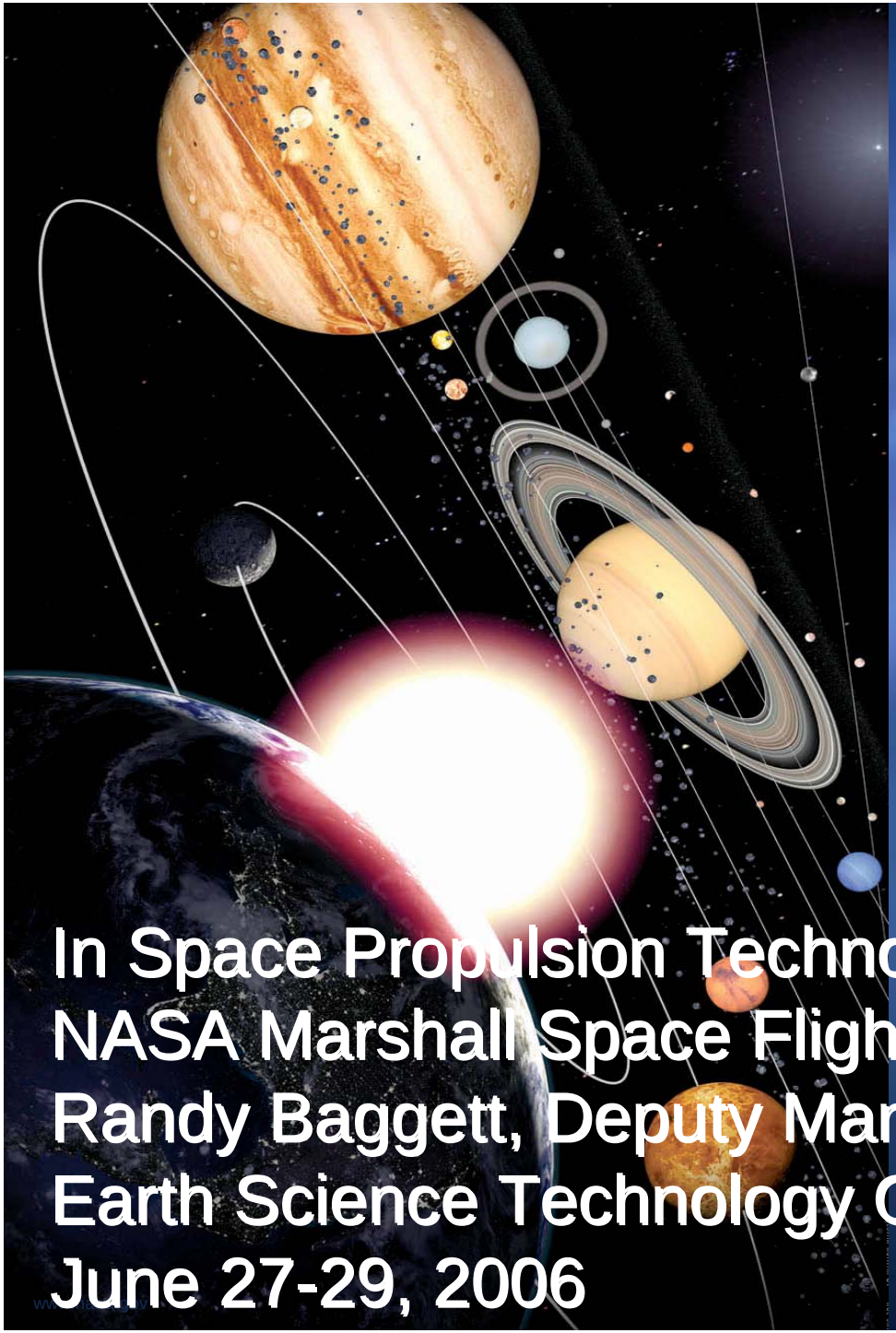
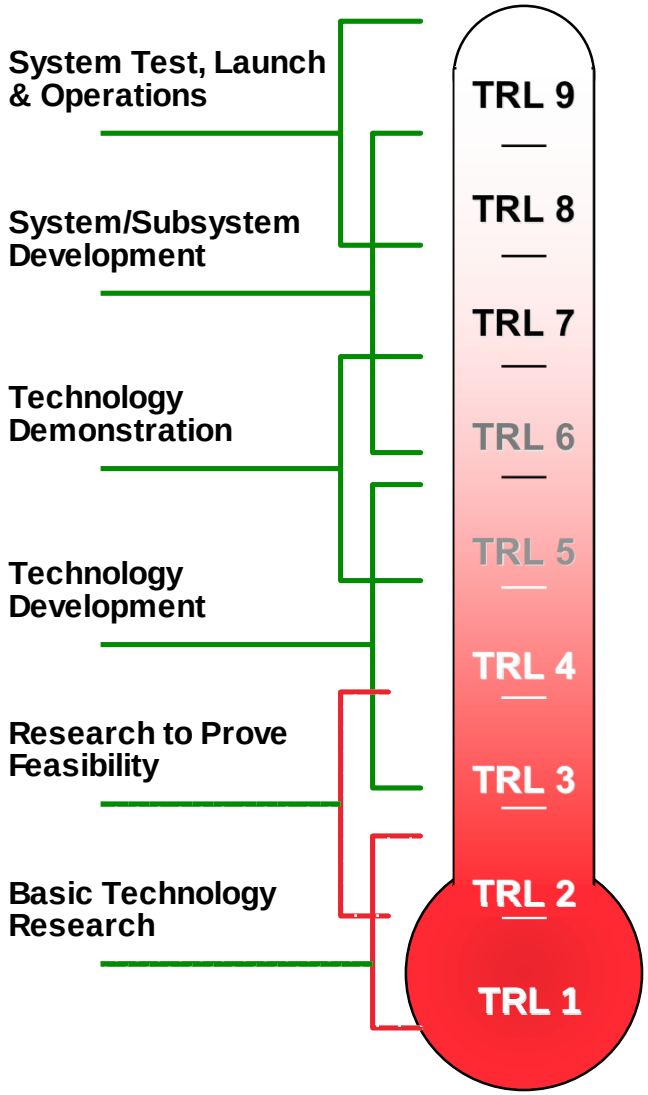
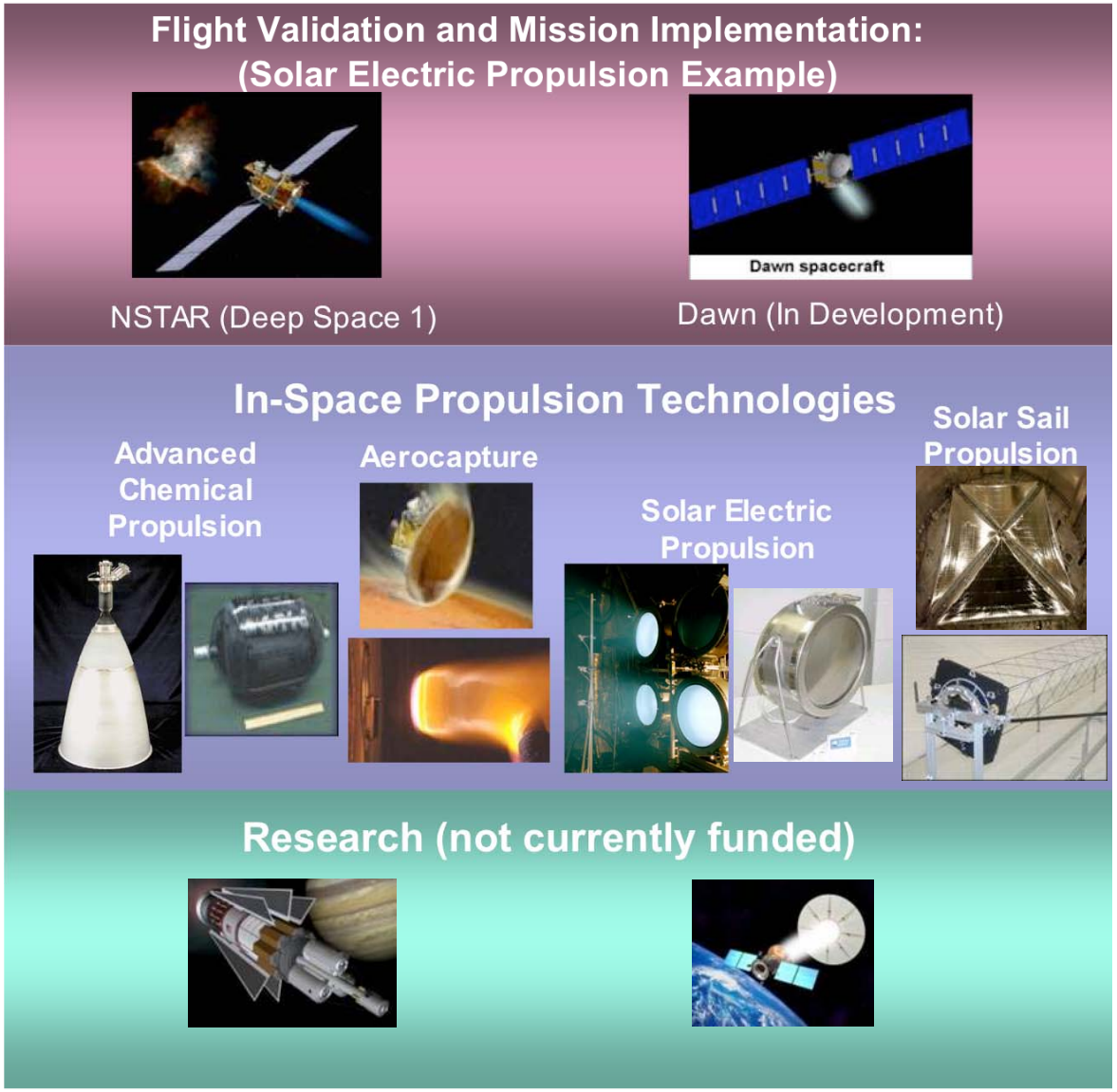


In Space Propulsion Technology Overview

In Space Propulsion Technology Project
NASA Marshall Space Flight Center
Randy Baggett, Deputy Manager
Earth Science Technology Conference 2006
June 27-29, 2006

ISP Project Focuses On Mid-TRL Propulsion System Development and Integration





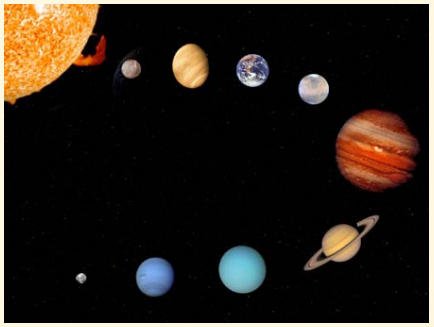
In-Space Propulsion Technology Program Summary

- **Program Structure:**
  - NASA's Science Mission Directorate, Planetary Science Division; Program Executive: Dave Lavery
  - *Implemented* by In-Space Propulsion Technology Project Office at MSFC

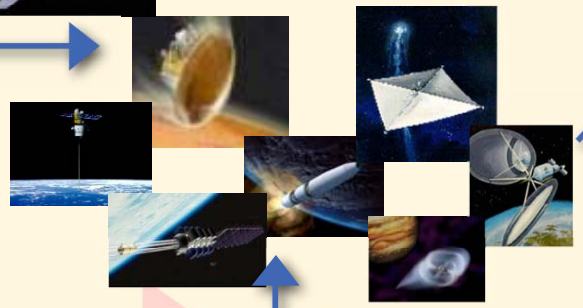
- **In-Space Propulsion Technology Project is in fifth year and is focused on delivering products in the areas of**
  - Aerocapture
  - Solar Electric Propulsion
  - Solar Sails
  - Advanced Chemical Propulsion
  - Emerging Technologies

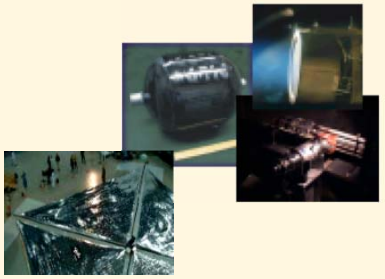
- **FY06 Funding: $26M**
- **www.inspacepropulsion.com**

ISP Prioritization Process
Integrated In-Space Transportation Planning



Technology Options Identified





Systems Concepts Compared

- Feasibility
- Identification of Technology Drivers
- Recommended approaches

Requirements/Goals Established

- Space Science
- Earth Science
- Exploration and Development

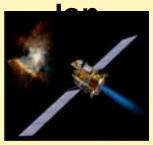
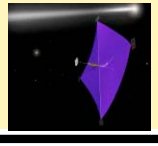
Requirements provided by NASA Enterprise customers

Systems Concepts Developed

- Architecture
- Safety/Reliability
- Cost, Trip Time, etc.

Technologies Prioritized

In-Space Propulsion Priorities (2002 to 2006)

High Priority	Medium Priority	Low Priority	High Payoff High Risk
Aerocapture 	Adv. Chem. 		1 g/m2 S. Sails 
Next Gen. Ion 	SEP <50 kW 	Solar Thermal 	MXER Tethers 
Solar Sails 	SEP Hall 100kW 		Plasma Sails 

ISP Priorities 2002

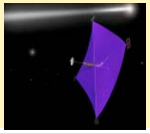
- Flagship mission propulsion needs
  - Outer planet destinations
  - Cross Agency needs
- Low level technology push

ISP Priorities 2006

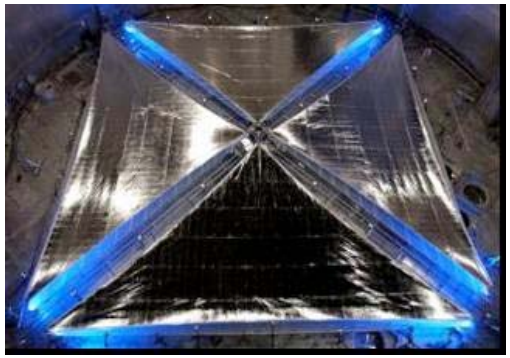
- Focus on Near term deliverables for SMD
- Address all mission-class propulsion

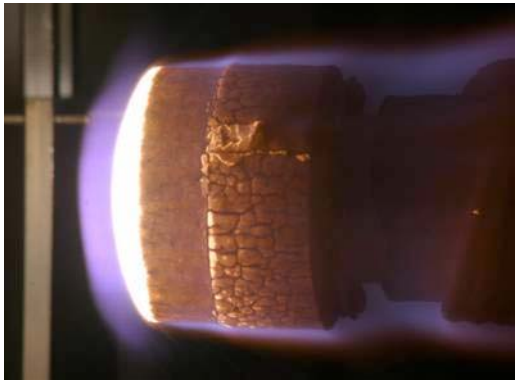
GOALS: - to enhance/enable science missions
- to lower cost

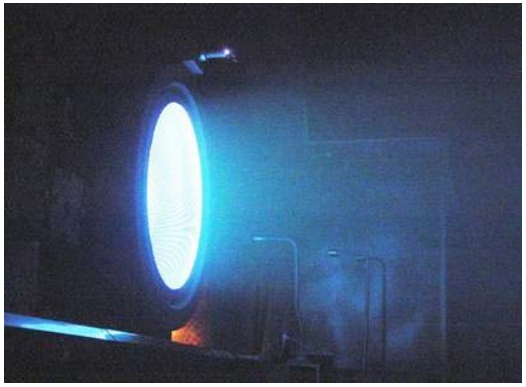
- All technologies linked to SMD mission pull

High Priority	Medium Priority	Low Priority	High Payoff High Risk
Aerocapture 	Adv. Chem. 		
Solar Electric 			
Solar Sails 			

In-Space Propulsion Technology Program







- **ISPT Program Objective:**
  - To develop in-space propulsion technologies that can enable and/or benefit near and mid-term NASA science missions by significantly reducing cost, mass, and/or travel times.
- **ISPT Project Implementation Approach:**
  - Identify and prioritize the most promising technologies using systems analysis and peer review.
    - Initial prioritization performed
    - Modifications based on customer changes (mission set and targeted customers), budget, and technology advancement success
    - Technical Assessment Groups, held yearly, help assess the technical challenges for each technology
  - Develop mid-TRL technologies to TRL 6 (planning to TRL 7) for incorporation into SMD mission planning
    - Maximize use of open competition to seek best solutions. Competitive procurements have been HQ released NRAs – Industry, Academia and NASA compete
    - Directed task budget is competitive among the Centers – focused on gap fillers or activities that only NASA can do.

Competed Technology Development

NRA	Amendment & Award FY	Award status	Technology area
Research Opportunities in Space Sciences (ROSS)	Next Generation Ion Engine Technology - FY02	2 awarded	EP/Ion
	In-Space Propulsion Technologies, Cycle 1 - FY02	6 awarded	Aerocapture
		3 awarded	Solar sails
		6 awarded	Electric Propulsion for NEP and Power Conversion
	In-Space Propulsion Technologies, Cycle 2 - FY03	2 awarded	Aerocapture
		4 awarded	Advanced Chemical
		2 awarded	kW SEP
		4 awarded	Momentum Exchange Tethers
		4 awarded	Solar Sails
	In-Space Propulsion Technologies, Cycle 3 - FY05	1 awarded	Advanced Chemical
Research Opportunities in Space and Earth Sciences (ROSES)	In-Space Propulsion Technologies, Cycle 4 - FY06	n/a	Cancelled due to budget cut

Technology Area Objectives & Plans

Aerocapture Technology Area

♦ Goals & Objectives

- To develop aerocapture systems for robotic exploration of the Solar System with current emphasis on near term, small body destinations and to validate those systems in relevant environments.

♦ Revised Development Plan

- Highest Priority is to support flight validation under NMP – Will validate GN&C and advanced TPS and offers risk mitigation that ground activities are unable to provide. If aerocapture technology is selected, gaps not addressed by flight will not be filled until after flight commitment completed.
- If flight opportunity not realized under the NMP ST9 opportunity – development strategy is to continue to reduce risk on the ground with acceptable cost/benefit
  - Address gaps associated with current developments of TPS – long term environmental evaluation, shear and spallation testing, fabrication of large scale articles.
  - Develop GN&C – Further develop the GN&C algorithms and software and perform hardware in the loop testing.
  - Continue to address modeling and tools to reduce level of uncertainties that currently would have to be addressed with robust design margins.
- Investigating possibilities of component and subsystem infusion of technologies into non-aerocapture applications: entry probes, instrumentation infusion, etc.

Solar Electric Propulsion Technology Area

Goals & Objectives

- Focus on development and validation of systems & subsystems to allow science missions to take full advantage of the benefits that electric propulsion has to offer by reducing cost and risk to the end user.
  - Benefits Discovery/New frontiers and flagship mission classes

Revised Development Plan

- Complete development of the NEXT ion engine (with exception of life test) in FY07.
- Fund activities in FY07 that will allow down-select and begin implementation of cost savings technology investments:
  - Hall thrusters
  - Standard Architecture
  - Commercial EP utilization
  - Long duration life test strategy

Solar Sail Propulsion Technology Area

Goals & Objectives

- To infuse solar sail propulsion technology into a NASA science mission through development, demonstration and mission benefit analyses.
  - Support flight demonstration through NMP ST9
  - Address technology gaps remaining after 20m Ground Demonstration

Revised Development Plan

- Offer attitude control system, spacecraft charging and engineering and test support (expertise based on ISP-funded ground demonstrations) to the Solar Sail NMP Proposal. (This is far below the pre-budget cut plan to provide the flight Sail to the proposed NMP mission)
- In both FY07 and FY08 continue to fill technology gaps that were identified or not completed with the ground system demonstrations of 20 meter solar sails. Gaps addressed in FY08 will be those not fulfilled by flight demonstration efforts if Solar Sail proposal selected under NMP.
- Focus on developing a strategic approach to filling remaining gaps under scenarios with and without an NMP flight of Solar Sails. Advocate for customer (Heliophysics Division) funding support of this technology in the out-years.

Advanced Chemical Propulsion Technology Area

Goals & Objectives

- Develop evolutionary advanced propellant; lightweight and optimized components; and subsystem and manufacturing technologies that offer near- and mid-term measurable system level benefits which result in higher performance or increased reliability by
  - Identifying technologies which rapidly advance SOA chemical systems
  - Focusing development and near term delivery of a single product every 2 to 3 years

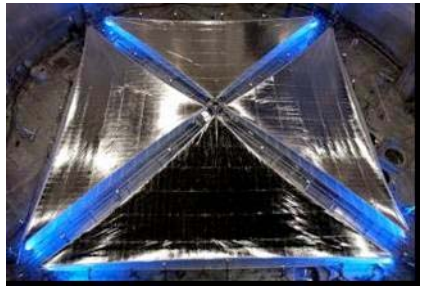
Revised Development Plan

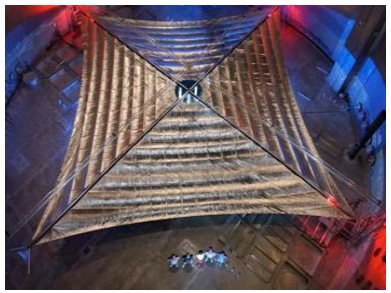
- Focus on single product delivery every 2 to 3 years. Small amount of funding to go to "proof of benefit" type efforts to drive out decision on next product solicitation (combination of technical and systems analysis effort)
- Improvements in thruster performance through further development and testing of the High Temperature Thruster (Cycle 3 NRA) will be primary product development for FY07 and FY08.
- Future efforts may include Advanced Lightweight Tank Technology Development and Pressurization and Mixture Ratio Control

In Space Products
"TO DATE and TO COME"

TO DATE

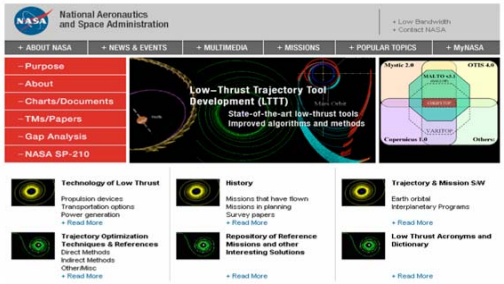
Two 20 Meter Ground System Demonstrator Solar Sails





FY05

Low Thrust Trajectory Tool Suite



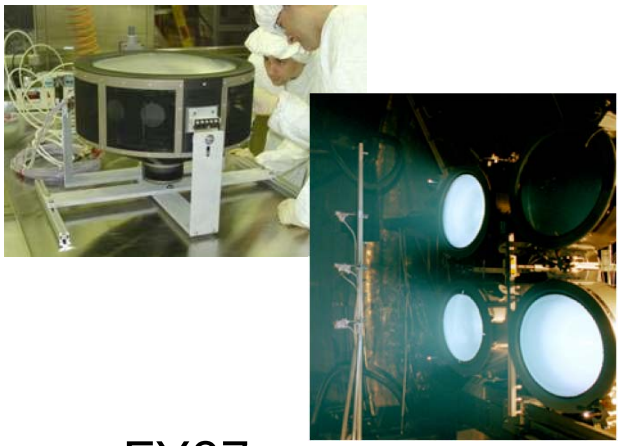
FY06

TO COME

Integrated Advanced Aeroshells For Aerocapture

FY06

NEXT Ion Engine



FY07

High Temperature Chemical Thruster

FY08

Systems Analysis

Goals & Objectives

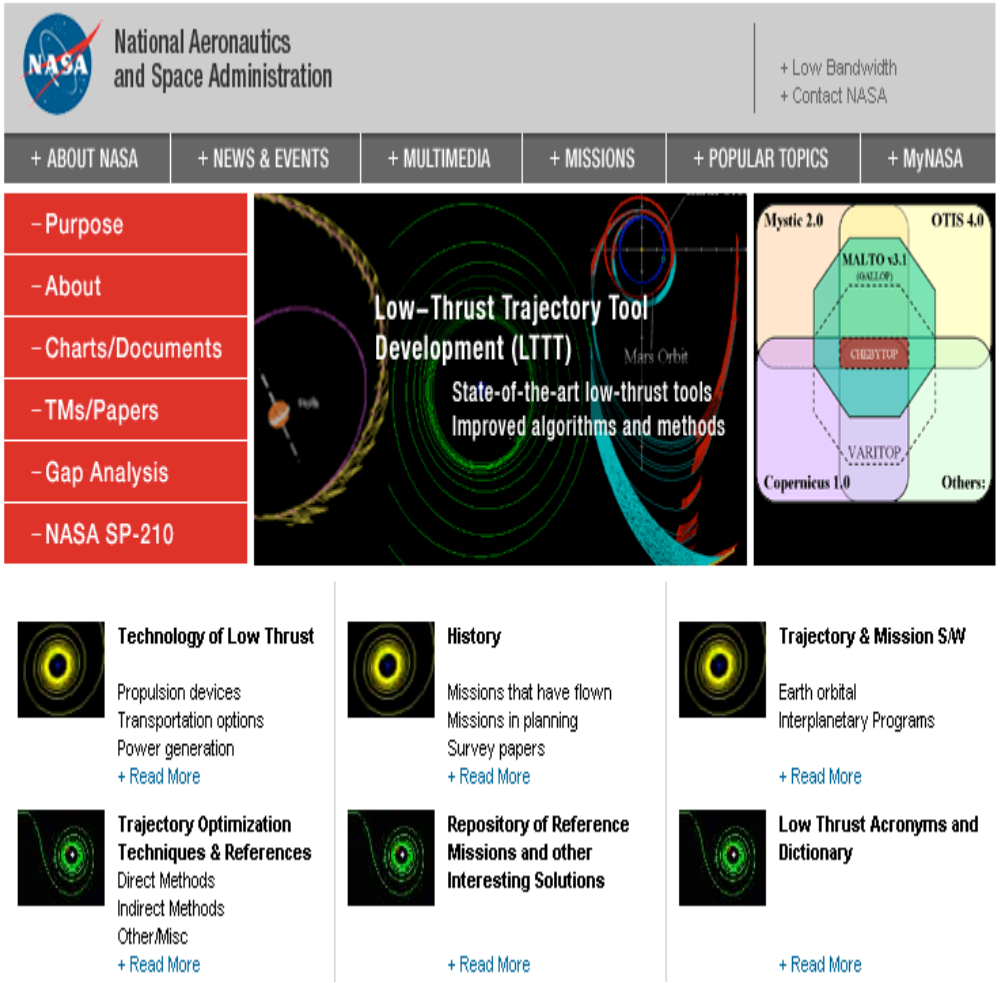
- Support ISP Investment decisions by
  - Providing analysis results and quantified inputs to support investment decisions
  - Driving out technology development challenges
  - Developing and maintain systems analysis tools

Revised Development Plan

- Maintain flexibility to address system studies at both Mission evaluation and technology requirement development levels.
  - Mission and systems studies will be coordinated to provide customer driven technical requirements and proposed technology improvements will be evaluated against mission performance
  - Technology Area input will provide main driver for study selection in the absence of changes in customer roadmap missions.

Low Thrust Trajectory Tool (Example Systems Analysis Product)

- The **Low Thrust Trajectory Tool (LTTT)** developed by a multi-center team including GRC, JPL, JSC, and led by MSFC is a state-of-the-art suite of low-thrust tools and improved algorithms and methods which include MALTO, Mystic, OTIS, SNAP, and Copernicus.
- **LTTT** enhances NASA and Industry mission analysis capabilities by providing trajectory generation/optimization tools for low thrust propulsion technologies.
- **LTTT** enables mission trajectory analysts to produce uniform results across all NASA centers and ISP support centers to run equivalent analyses for propulsion technology trade studies and mission trade studies.
- **LTTT** is:
  - Rapid and accurate which reduces time required for quick looks and detailed analysis
  - User friendly, well documented and available for monitored dissemination to US parties (ITAR, EAR)
  - Applicable to a wide range of mission and levels of difficulty (Pre Formulation to Mission Design)



"LTTT Website"

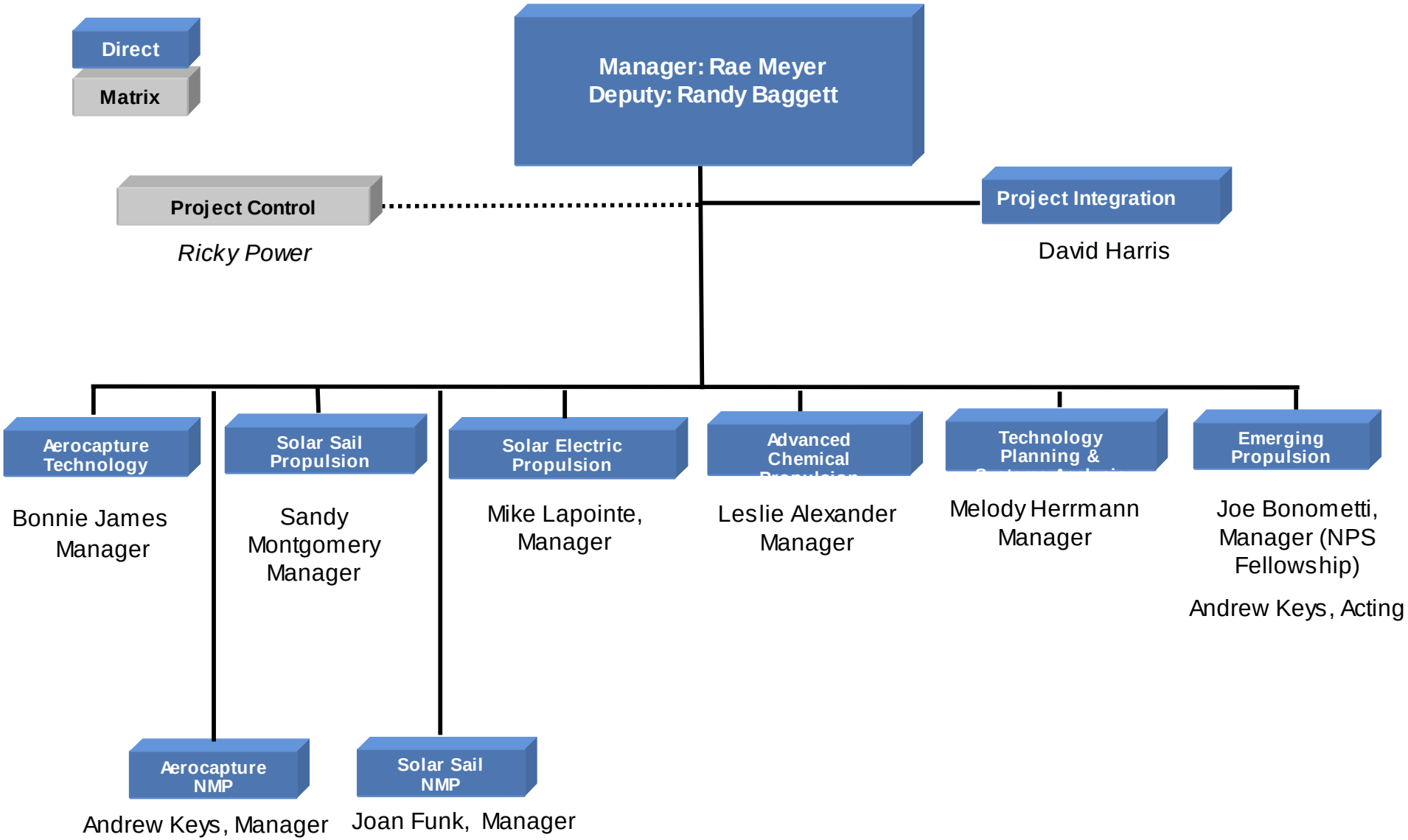
ISP Plans for Flight Infusion

- **ISP has responsibility for *planning* technology maturation beyond TRL-6**
  - Enhanced scope means roadmapping to TRL-7 and beyond
    - Previous objective was technology maturation to TRL 6
    - ***Note: Planning for TRL-7 does not equate with the responsibility for funding development to TRL-7***
  - Requires a different way of thinking for a “traditional” technology program
    - Satisfying potential first mission customer’s assessment of high-risk items becomes very important
  - Technology flight validation experiments must be traced to SMD missions.

In-Space Propulsion Partnering

- **ISP continues support to ST 9 partnering with New Millennium Program, through Core Team participation and funding, for the possible flight validation of several key technologies**
  - Aerocapture and Solar Sail Propulsion are among five technologies vying for the ST-9 flight opportunity
  - Aerocapture Flight Validation Experiment
    - ISPT will fund, manage the procurement and conduct of contracted efforts for the development and delivery of the aeroshell and thermal protection subsystems for integration into the final flight system.
    - JPL is the flight center
  - Solar Sail Flight Validation Experiment
    - ISPT will fund expertise in the areas of sail attitude control system design and analysis, fabrication and processing, space durability, structural analysis, charging environments, thrust prediction, and test and integration.
    - GSFC is the flight center
  - FY06 activities focus on the Phase A study and proposal development
    - MOU defining ISP commitment to Solar Sail and Aerocapture ST-9 proposals expected to be signed by NASA HQ's
  - Selection anticipated in late December of 2006

ISPT Organization (VP51)



For additional information on the In Space Propulsion Technology Project, please contact:

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